Appendix C
Design of Seepage Berms

C-1. General

This appendix presents design factors, equations, criteria, and examples of designing landside seepage berms. A discussion of the four major types of landside seepage berms is presented in the main text of this manual. The design equations presented are taken from U.S. Army Engineer Waterways Experiment Station TM 3-424 and EM 1110-2-1901 (Appendix A). Design procedures are taken from TM 3-424 and from procedures developed by the Lower Mississippi Valley Division (Appendix A).

C-2. Design Factors

a. Seepage records, if available, should be studied to determine the severity of the underseepage conditions during high water. A projection based upon these records of underseepage during high water to the design flood should be made based on experience and judgment. Aerial photographs and borings should be used to evaluate geologic and soil conditions. The location of drainage ditches and borrow pits should be noted and considered in design. Additional borings should be made where required to determine in situ soil and geological data needed for design.

b. The distance s from the landside toe of the levee to the point of effective seepage entry is equal to the base width of the levee L_2 plus the effective length of blanket x_1 on the riverside of the levee. The effective length of blanket x_1 can be determined by using blanket equations presented in Appendix B. The effect of riverside borrow pits or natural low areas such as oxbows, must be considered in determining x_1. The effective length of blanket x_1 should be the lesser of the distance based on the blanket thickness outside the riverside borrow pit and the distance based on the blanket thickness inside the riverside borrow pit plus the distance from the riverside toe of the levee to the borrow pit. The blanket equations assume an infinite blanket length. However, this assumption may not be valid if the river is close to the levee. If the computed value of x_1 is greater than L_1 (distance from riverside toe of levee to the river), then x_1 should equal L_1 . Distances to effective sources of seepage, effective lengths of riverside blankets, and vertical permeabilities of riverside blanket materials at different sites along the Mississippi River at the crest of the 1950 high water period are given in Table C-1. The values of x_1 are observed values adjusted to an assumed condition of a riverside blanket of infinite length with the same thickness as that of the borrow pit. The adjustment was made by use of blanket equations presented in Appendix B to partially eliminate the effect of different top strata riverward of the borrow pits and different distances between the levee and river at various sites.

c. The thickness d and permeability k_f of the pervious materials between the bottom of the blanket and the entrenched valley must be determined before designing a seepage berm. In Appendix B, paragraph B-4c, methods are described for determining d and k_f.

d. The permeability k_{bl} and effective thickness z_{bl} of the landside blanket must be determined before the seepage exit length x_3 can be computed. If the blanket is composed of more than one stratum and the vertical permeability of each stratum is known, the thickness of each stratum of the blanket can be transformed into an equivalent thickness of material having the same permeability as for one of the strata. A procedure and example for transforming the actual thickness of a stratified blanket into an effective thickness z_{bl} with a uniform vertical permeability is described in Appendix B, paragraph B-4b(2). The critical thickness of the landside top stratum z_t that should be used to determine if uplift pressure is within safe limits may or may not be equal to z_{bl} for stratified layers. The procedure and examples for computing z_t for different conditions of soil stratification are also presented in Appendix B, paragraph B-4b(2).

Table C-1a
Summary of Distances to Effective Source of Seepage, Effective Lengths of Riverside Blankets, and Vertical Permeability of Riverside Blanket Materials at the Crest of 1950 High Water (Metric Units)

Soil Type	Blanket in Riverside Borrow Pit Thickness in m	Number of Piezometer Lines from Which Data Were Obtained	S, m Max	S, m Min	S, m Avg	x_1, m[a] Max	x_1, m[a] Min	x_1, m[a] Avg	k_{br} x 10^{-4} cm/sec Max	k_{br} x 10^{-4} cm/sec Min	k_{br} x 10^{-4} cm/sec Avg	Suggested Design Values k_{br}	Suggested Design Values x_1, m		
Sand --	3	304.8		243.8	292.6	146.3		61	112.8	–	–	–	–	76.2	
Silty sand[b]	<1.52	3		243.8	170.7	204.2		97.5	70.1	85.3	14.2	1.6	7.0	7.0	91.4
	1.52 to 3.05	1		170.7	170.7	170.7		85.3	85.3	85.3	1.8	1.8	1.8	2.5	182.9
													5.7[c]		
Silt and sandy silt	<1.52	4		457.2	182.9	320		371.8	83.3	204.2	7.4	0.24	2.2	2.0	121.9
	1.52 to 3.05	2		487.7	277.4	384		362.7	155.4	259.1	5.0	0.33	2.7	1.5	243.8
															365.8
	>3.05												2.4[c]	1.0	
Clay	<1.52	6		390.1	185.9	310.9		228.6	33.6	210.3	1.7	0.34	0.79	0.8	182.9
	1.52 to 3.04	2		524.3	463.3	493.8		387.1	326.1	356.6	1.3[d]	0.86[d]	1.08[d]	0.5	396.2
	3.05 to 4.58	2		–	–	–		–	–	–	–	–	–	0.2	762.0
	>4.58	3		960.1	243.8	487.7		∞	∞	∞	0.0	0.00	0.00	0.05	1219.2[e]
													0.4[c,f]		or L_1

[a] Values of x_1 computed from observed values of x_3 and adjusted to a condition where $L_1 = \infty$.
[b] Does not include Hole-in-the-Wall where values of S and x_1 may not be reliable because artesian flow conditions did not develop until near the crest of the 1950 high water.
[c] Averages of all values of k_{br} for a given soil type without regard to thickness.
[d] Values are considered to be too high as at these piezometer lines (Upper Francis) seepage could enter the pervious substratum through a silty blanket riverward of the borrow pit as well as through the clay in the borrow pit.
[e] Use the smaller of the two values.
[f] Average does not include k_{br} for blanket thickness between 1.52 and 3.05 m.

Table C-1b
Summary of Distances to Effective Source of Seepage, Effective Lengths of Riverside Blankets, and Vertical Permeability of Riverside Blanket Materials at the Crest of 1950 High Water (English Units)

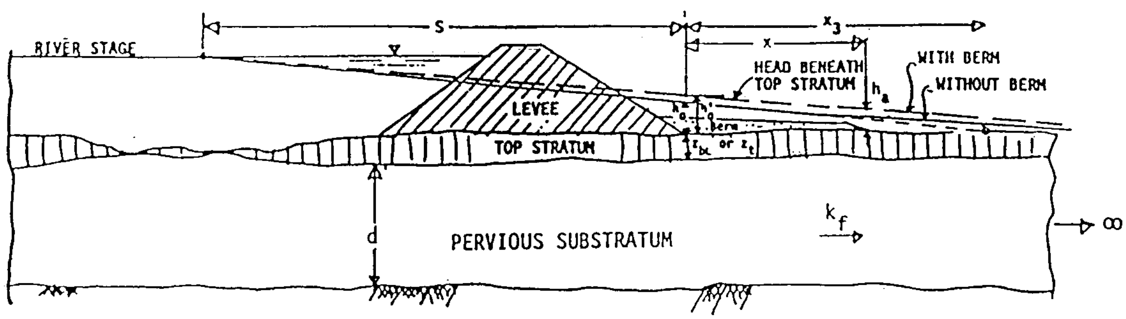
Soil Type	Blanket in Riverside Borrow Pit Thickness in ft	Numer of Piezometer Lines from Which Data Were Obtained	S, ft Max	S, ft Min	S, ft Avg	x_1 ft[a] Max	x_1 ft[a] Min	x_1 ft[a] Avg	k_{br} x 10^{-4} cm/sec Max	k_{br} x 10^{-4} cm/sec Min	k_{br} x 10^{-4} cm/sec Avg	Suggested Design Values k_{br}	Suggested Design Values x_1 (ft)
Sand --	3	1080	800	960	480	200	370	--	--	--	--	250	
Silty sand[b]	<5	3	800	560	670	320	230	280	14.2	1.6	7.0	7.0	300
	5 to 10	1	560	560	560	280	280	280	1.8	1.8	<u>1.8</u> 5.7[c]	2.5	600
Silt and sandy silt	<5	4	1500	600	1050	1220	270	670	7.4	0.24	2.2	2.0	400
	5 to 10	2	1600	910	1260	1190	510	850	5.0	0.33	<u>2.7</u>	1.5	800 1200
	>10										2.4[c]	1.0	
Clay	<5	6	1280	610	1020	750	110	690	1.7	0.34	0.79	0.8	600
	5 to 10	2	1720	1520	1620	1270	1070	1170	1.3[d]	0.86	1.08	0.5	1300
	10 to 15	0	--	--	--	--	--	--	--	--	--	0.2	2500
	>15	3	3150	800	1600	∞	∞	∞	0.0	0.00	<u>0.00</u> 0.4[c,f]	0.05	4000 or L_1[e]

[a] Values of x_1 computed from observed values of x_1 and adjusted to a condition where $L_1 = \infty$.
[b] Does not include Hole-in-the-Wall where values of S and x_1 may not be reliable because artesian flow conditions did not develop until near the crest of the 1950 high water.
[c] Averages of all values of k_{br} for a given soil type without regard to thickness.
[d] Values are considered to be too high as at these piezometer lines (Upper Francis) seepage could enter the pervious substratum through a silty blanket riverward of the borrow pit as well as through the clay in the borrow pit.
[e] Use the smaller of the two values.
[f] Average does not include k_{br} for blanket thickness between 5 and 10 ft.

e. The seepage exit length x_3 can be calculated from equations presented in Appendix B, paragraph B-4g. These equations are applicable to conditions where the length of the landside blanket L_3 is either infinite or finite.

C-3. Design Equations and Criteria

a. Design equations. Equations for the design of landside seepage berms for the four major berm types are presented in Figure C-1. These equations are valid when a landside blanket of infinite length exists. A discussion of the four major landside seepage berms is presented in paragraph 5-4.



Notations

$C = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$

γ'_z = submerged unit weight of top stratum

γ'_t = submerged unit weight of berm

γ_w = unit weight of water

H = total net head on levee

h_o = head at landside toe of levee without berm = $\dfrac{Hx_3}{s + x_3}$

h'_o = head at landside toe of levee with berm

i_o = allowable upward gradient at landside toe of levee

i_1 = allowable upward gradient at toe of berm

h_a = allowable head at toe of berm = $i_1 \cdot z_t$

X = required berm width

t = required thickness of berm at toe of levee

k_t = vertical permeability of berm

F = factor of safety against uplift at toe of levee

Q_b = flow into berm per foot of levee

s = distance from landside toe of levee to effective source of seepage entry

x_3 = distance from landside toe of levee to effective source of seepage exit

d = effective thickness of pervious substratum

Formulas

Impervious Berm, $k_t = 0$

$$X_I = x_3\left(\frac{H}{h_a} - 1\right) - s$$

$$h'_o = H\left(\frac{x_3 + X}{s + x_3 + X}\right)$$

$$t = \frac{h'_o - z_t\left(\dfrac{\gamma'_z}{F\gamma_w}\right)}{1 + \dfrac{\gamma'_t}{F\gamma_w}}$$

USE $F \geq 2.8$

Semipervious Berm, $k_t = k_{bl}$

$$X_{sp} = \frac{-A + \sqrt{A^2 - 24(2 + r)\left(1 + sc - \dfrac{H}{h_a}\right)}}{2c(2 + r)}$$

where:

$$A = 6 + 3sc(r + 1)$$

$$r = i_o/i_1$$

$$h'_o = h_a\left[1 + c \cdot X + \left(\frac{2 + r}{6}\right)(cX)^2\right]$$

$$t = \frac{h'_o - i_o z_t}{1 + i_o}$$

Sand Berm

$$X_s = \frac{1}{3}(X_p + 2X_{sp})$$

$$h'_o = h_a\left[1 + cX + \left(\frac{2 + r}{6}\right)(cX)^2\right]$$

$$t = \frac{h'_o - z_t\left(\dfrac{\gamma'_z}{F\gamma_w}\right)}{1 + \dfrac{\gamma'_t}{F\gamma_w}}$$

Pervious Berm with Collector

$$X_p = x_3 \log_e\left(\frac{h'_o}{h_a}\right)$$

$$h'_o = h_o = \frac{Hx_3}{s + x_3}$$

$$t = \frac{h'_o - z_t\left(\dfrac{\gamma'_z}{F\gamma_w}\right)}{1 + \dfrac{\gamma'_t}{F\gamma_w}}$$

$$Q_b = \frac{k_f H d}{s + x_3}\left(1 - e^{-\frac{X}{x_3}}\right)$$

Figure C-1. Design of landside seepage berms on impervious top stratum

b. Design criteria

(1) Where a levee overlies a top stratum creating a landside blanket and the upward gradient through the blanket at the landside toe of the levee is greater than 0.8, a seepage berm should be designed with an allowable upward gradient of 0.3 through the blanket and berm at the landside toe of the levee. For a

saturated unit soil weight of 1840 kg/m^3 (115 pcf), this is equivalent to a factor of safety of 2.8. The factor of safety of 2.8 applies only to new construction, not to existing projects. A factor of safety lower than 2.8 may be used, based on sufficient soil data and past performance in the area. The berm width should be based on an allowable upward gradient of 0.8 through the top stratum at the landside toe of the berm, subject to the limitations in the paragraphs which follow. The thickness of the berm should be increased 25 percent to allow for shrinkage, foundation settlements and variations in design factors. Where field observations during lesser floods indicate severe seepage problems would occur at the design flood, the berm dimensions should be extended.

(2) All berms should have minimum thickness of 1.52 m (5 ft) at the levee toe, a minimum thickness of 0.61 m (2 ft) at the berm crown, and a minimum width of 45.7 m (150 ft).

(3) For conditions where the computed upward gradient at the landside toe of the levee is between 0.5 and 0.8 without a berm, a berm with minimum dimensions as specified in (2) above should be constructed. Also for conditions where the computed gradient is less than 0.5, but either severe seepage has been observed or seepage is expected to become severe and soften the landside portion of the levee, the minimum berm should be constructed.

(4) The width of the berm is usually limited to about 91.4 to 121.9 m (300 to 400 ft), although the design calculations may indicate that a greater berm width is required. When the selected width of the berm is less than the calculated width, using berm design equations of Figure C-1, the head h_o' and berm thickness t at the levee toe will be less than for the computed width. For the selected berm, h_o' should be recomputed assuming an i_1 of 0.8 at the toe of the new berm and a linear piezometric grade line between the toe of the new berm and the point of effective seepage entry. The design thickness of the selected berm at the toe of the levee and the estimated seepage flow under the levee will be based on the value of h_o' corresponding to the selected berm.

(5) For conditions where no landside blanket exists, the necessity for a landside seepage berm will be based on the exit gradient and seepage velocity as discussed in paragraph B-5b. The berm thickness at the landside toe should be of such magnitude that the upward gradient i_o does not exceed 0.3. The design thickness of the berm should be increased by 25 percent to allow for shrinkage, foundation settlements, and variations in design factors. The head h_o' beneath the berm at the landside toe of the levee can be determined from Equation C-1.

$$h_o' = \frac{H(X + 0.43\ \overline{D})}{x_1 + L_2 + X + 0.43\ \overline{D}} \tag{C-1}$$

In the above equation $\overline{D}$ is the transformed thickness of the pervious stratum which is equal to $d\sqrt{k_h/k_v}$, L_2 is the base width of the levee, H is the total net head on levee, X is the berm width, and x_1, is the effective length of impervious blanket riverside of the levee. If no riverside blanket exists, the value of x_1 is assumed to be 0.43 $\overline{D}$. The rate of seepage Q_s below the levee per unit length of levee can be determined using Equation C-2.

$$Q_s = \frac{k_f H d}{x_1 + L_2 + X + 0.43\ \overline{D}} \tag{C-2}$$

In the equation above, k_f is the permeability of the pervious substratum and d is the effective thickness of the pervious substratum. H , x_1 , L_2 , X , and $\overline{D}$ are as previously defined. If Q_s exceeds 757.1 ℓ/min (200 gal/min) per 30.5 m (100 ft) of levee, a riverside blanket should be designed to reduce the seepage. Riverside blankets are discussed in paragraph 5-3.

(6) The slope of berms should be generally 1V on 50H or steeper to ensure drainage. If the berm is constructed after the levee has caused the foundation to consolidate fully, a slope of 1V on 75H can be used. Where wide, thick berms are required, consideration may be given to using a berm with a broken surface slope to more closely simulate the theoretical thickness and consequently reduce the cost of the berm. Where this is done, the steeper riverward slope of the berm should be no flatter than 1V on 75H and the landward slope of the berm should be no flatter than 1V on 100H.

(7) In short reaches where computations indicate no berm is necessary, but berms are required in adjacent reaches, it may be advisable to continue the berm construction through such reaches due to concentration of seepage in these areas. Also, in areas where entrance conditions in adjacent reaches are highly variable, potential adverse effects of close entry in adjacent reaches should be taken in to consideration.

C-4. Design Example

An example design problem with solution is presented in Table C-2 illustrating the design of impervious, semipervious, sand, and free draining landside seepage berms overlaying a thin landside top stratum. Each berm is designed for the same conditions using the design equations and design criteria as presented in this appendix.

Table C-2a
Examples of Design of Seepage Berms (Metric Units)

Designs based on following conditions:

H = 7.6 m	z_{bl} = z_t = 1.83 m	γ' = 840.5 kg/m³ for impervious berms
k_f = $1{,}000 \times 10^{-4}$ cm/sec	i_o = 0.30	γ' = 920.6 kg/m³ for sand berm or pervious berm with collector, F = 1.6
d = 30.5 m	i_1 = 0.80	F = 1.6 for impervious berm
k_{bl} = 3×10^{-4} cm/sec	γ' = 840.5 kg/m³	L_3 = ∞
s = 304.8 m	x_3 = 137.2 m	

	Required Berm			Suggested Design Dimensions				Suggested Construction Dimensions			Approximate[d] Material
Type Berm	Width X, m	Thickness[a] t, m	h_o'[b] m	Thickness at Berm Crown m	Berm Width X, m	Berm Slope	Approximate Thickness Levee Toe m	Thickness[c] at Berm Crown m	Berm Width X, m	Thickness[c] at Levee Toe m	Required m³ per 100 m of Levee
Impervious	268.2	2.22	4.33	0.61	243.8[e]	1 on 75	3.87	0.76	243.8	4.85	73,266
		1.49	3.23	0.61	121.9	1 on 75	2.22	0.76	121.9	2.77	23,312
Semipervious	85.34	1.16	2.62	0.61	83.82	1 on 75	1.74	0.76	83.82	2.16	13,321
Sand	79.20	1.0	2.53	0.61	76.20	1 on 75	1.61	0.76	76.20	2.01	11,528
Pervious with collector	65.53	0.88	2.35	0.61	60.96	1 on 75	1.43	0.76	60.96	1.80	8,454[f]

[a] At toe of levee.
[b] Head at toe of levee with berm, measured above surface of natural ground.
[c] Thickness increased 25 percent for shrinkage, foundation settlements, and variations in design factors.
[d] Calculations based on suggested construction dimensions.
[e] Berm width considered longer than necessary. If boils developed 121.9 m or farther landward of the toe of the levee, the levee probably would not be endangered. Therefore, an alternate design for an impervious berm with a width of 121.9 m is also given.
[f] Sand and gravel blankets and collector system are also required.

Table C-2b
Examples of Design of Seepage Berms (English Units)

Designs based on following conditions:

H	=	25 ft	z_{bl}	=	z = 6.0 ft	ã′	=	52.5 pcf for impervious berms
k_f	=	$1,000 \times 10^{-4}$ cm/sec	i_o	=	0.30	ã′	=	57.5 pcf for sand berm or pervious berm with collector, F = 1.6
d	=	100 ft	i_1	=	0.80	F	=	1.6 for impervious berm
k_{bl}	=	3×10^{-4} cm/sec	ã′	=	52.5 pcf	L_3	=	∞
s	=	1,000 ft	x_3	=	450 ft			

	Required Berm			Suggested Design Dimensions				Suggested Construction Dimensions			Approximate[d] Material
Type Berm	Width X, ft	Thickness[a] t, ft	h_o' ft	Thickness at Berm Crown ft	Berm Width X, ft	Berm[b] Slope	Approximate Thickness Levee Toe ft	Thickness[c] at Berm Crown ft	Berm Width X, ft	Thickness at Levee Toe ft	Required yd per 100 ft of Levee
Impervious	880	7.3	14.2	2.0	800[e]	1 on 75	12.7	2.5	800	15.9	28,600
		4.9	10.6	2.0	400	1 on 75	7.3	2.5	400	9.1	9,100
Semipervious	280	3.8	8.6	2.0	275	1 on 75	5.7	2.5	275	7.1	5,200
Sand	260	3.3	8.3	2.0	250	1 on 75	5.3	2.5	250	6.6	4,500
Pervious with collector	215	2.9	7.7	2.0	200	1 on 75	4.7	2.5	200	5.9	3,300[f]

[a] At toe of levee.
[b] Head at toe of levee with berm, measured above surface of natural ground.
[c] Thickness increased 25 percent for shrinkage, foundation settlements, and variations in design factors.
[d] Calculations based on suggested construction dimensions.
[e] Berm width considered longer than necessary. If boils developed 400 ft or farther landward of the toe of the levee, the levee probably would not be endangered. Therefore, an alternate design for an impervious berm with a width of 400 ft is also given.
[f] Sand and gravel blankets and collector system are also required.